

Figure 12 is an exemplary tabular diagram illustrating improved performance margins under various conditions utilizing the correlated noise reduction apparatus of the present invention. Simulations at Adtran, Inc. were conducted to evaluate the performance improvement by employing a noise predictor of the present invention within an existing HDSL2 system. Correlated crosstalk environments 720 included environment 700 (24 T1 lines plus 24 HDSL2 (C) lines), environment 705 (39 HDSL2 (C) lines), environment 710 (24 ADSL lines plus 24 HDSL(C) lines), and environment 715 (24 T1 lines plus 24 HDSL2 (R) lines). Experimental measurements found that the performance margin improves approximately 1.5 dB (column 735) on average for most of the correlated crosstalk noise environments as specified in the HDSL2 standard.

Numerous advantages of the present invention may be apparent from the discussion above. First, the correlated noise reduction embodiments of the present invention substantially reduce correlated or non-white noise in data reception and transmission, and provide a significant increase in performance of 1-2 dB. The correlated noise reduction apparatus provides a third level of correlated noise reduction, following two levels of equalization, and is readily adaptive, converging quickly to optimal linear filter values without excessive training time. The various correlated noise reduction embodiments of the present invention provide noise whitening within a system utilizing a trellis decoder, and also with transmission-side precoding. In addition to providing precoding coefficients, the preferred correlated noise reduction embodiments of the present invention provide adaptive functionality during data transmission, to adjust to changing noise levels and spectral distributions.

From the foregoing, it will be observed that numerous variations and modifications may be effected without departing from the spirit and scope of the novel concept of the invention. It is to be understood that no limitation with respect to the specific methods and apparatus illustrated herein is intended or should be inferred. It is, of course, intended to cover by the appended claims all such modifications as fall within the scope of the claims.

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It is claimed:

1. An apparatus for correlated noise reduction, the apparatus comprising:
a trellis decoder, the trellis decoder operative to provide decoded data and
a trellis error signal, the trellis error signal formed as a decision error of a selected
5 previous state of a selected trellis path;
a linear feedforward equalizer, the linear feedforward equalizer having as
input a received data signal, the linear feedforward equalizer operatively coupled to the
trellis decoder for adaptation to the trellis error signal to modify a first plurality of
equalization coefficients $a(n)$; and
10 a noise predictor, the noise predictor operatively coupled to the linear
feedforward equalizer to provide an input to the trellis decoder, the noise predictor having
as input a tentative error signal, the tentative error signal formed as a difference between
a tentative symbol decision and a delayed received data signal subsequent to equalization,
the noise predictor operatively coupled to the trellis decoder for adaptation to the trellis
15 error signal to modify a plurality of correlated noise reduction coefficients $c(n)$.

2. The apparatus of claim 1, wherein the trellis decoder is further operative to
determine a plurality of trellis paths, to determine a cumulative error associated with each
trellis path of the plurality of trellis paths, and to select a trellis path, from the plurality of
20 trellis paths, having a smallest cumulative error, to form the selected trellis path.

3. The apparatus of claim 1, wherein the trellis decoder is further operative to
select an immediately previous state of the selected trellis path to form the selected
previous state.
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4. The apparatus of claim 1, wherein the tentative symbol decision and the
delayed received data signal subsequent to equalization have one symbol time delay.

5. The apparatus of claim 1, wherein for precoded data, an output of the
30 linear feedforward equalizer is filtered utilizing a transfer function of $(1 + C(z))$, wherein
 $C(z)$ is a z-transform of the correlated noise reduction coefficients $c(n)$.

6. The apparatus of claim 1, further comprising:
a decision feedback adaptive filter operatively coupled to an output of the
linear feedforward equalizer.

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7. The apparatus of claim 6, wherein for precoded data:
the trellis decoder further has a symbol decider operative during a training
mode to provide a symbol decision and a first training error signal, the first training error
signal formed as a difference between the symbol decision and a received training signal
10 subsequent to equalization and correlated noise reduction;
the linear feedforward equalizer further has as input the received training
signal during the training mode, the linear feedforward equalizer operatively coupled to
the trellis decoder for adaptation to the first training error signal during training mode to
provide the first plurality of coefficients $a(n)$ for equalization;

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the decision feedback adaptive filter is further operatively coupled to the
symbol decider for input of the symbol decision, for adaptation to the first training error
signal and to provide a second plurality of equalization coefficients $b(n)$; and

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the noise predictor, further having an output operatively coupled to a
combined output of the linear feedforward equalizer and the decision feedback adaptive
filter to provide an input to the symbol decider, the noise predictor having as input a
second training error signal, the second training error signal formed as a difference
between the symbol decision and the received training signal subsequent to equalization,
and the noise predictor operatively coupled to the symbol decider for adaptation to the
first training error signal to provide the plurality of correlated noise reduction coefficients
25 $c(n)$.

8.

The apparatus of claim 7, further comprising:

a processor operatively coupled to the decision feedback adaptive filter
and to the noise predictor, wherein the processor, when operative, is configured to
30 determine a plurality of precoding coefficients $t(n)$ as equal to a sum of the second
plurality of equalization coefficients $b(n)$ plus the plurality of correlated noise reduction

coefficients $c(n)$ plus the result of a convolution of the second plurality of equalization coefficients $b(n)$ with the plurality of correlated noise reduction coefficients $c(n)$ ($t(n) = b(n) + c(n) + b(n)*c(n)$); and

5 wherein the processor is further configured to transfer the plurality of precoding coefficients $t(n)$ to a transmitter for precoding of data for transmission.

9. The apparatus of claim 7, further comprising:

a first transmitter configured to transfer the plurality of equalization coefficients $b(n)$ and the plurality of correlated noise reduction coefficients $c(n)$ to a second transmitter for precoding using a plurality of precoding coefficients $t(n)$ determined by the second transmitter as equal to a sum of the second plurality of equalization coefficients $b(n)$ plus the plurality of correlated noise reduction coefficients $c(n)$ plus the result of a convolution of the second plurality of equalization coefficients $b(n)$ with the plurality of correlated noise reduction coefficients $c(n)$ ($t(n) = b(n) + c(n) + b(n)*c(n)$).

10. The apparatus of claim 1, wherein for non-precoded data:

the trellis decoder further has a symbol decider operative during a training mode to provide a symbol decision and a first training error signal, the first training error signal formed as a difference between the symbol decision and a received training signal subsequent to equalization and correlated noise reduction;

the linear feedforward equalizer further has as input the received training signal during the training mode, the linear feedforward equalizer operatively coupled to the trellis decoder for adaptation to the first training error signal during training mode to provide the first plurality of coefficients $a(n)$ for equalization; and

the noise predictor further has as input a second training error signal, the second training error signal formed as a difference between the symbol decision and the received training signal subsequent to equalization, and the noise predictor operatively coupled to the symbol decider for adaptation to the first training error signal to provide the plurality of correlated noise reduction coefficients $c(n)$.

11. The apparatus of claim 1, wherein the noise predictor is embodied as a linear adaptive filter operative with a least mean square algorithm.

12. An apparatus for correlated noise reduction, the apparatus having a 5 training mode and having a data mode, the apparatus operative during training mode to receive a training signal from a transmitter and operative during data mode to receive a data signal from the transmitter, the apparatus comprising:

10 a trellis decoder, the trellis decoder having a symbol decider operative during the training mode to provide a symbol decision and a first training error signal, the first training error signal formed as a difference between the symbol decision and a received training signal subsequent to equalization and correlated noise reduction, the trellis decoder operative during the data mode to provide decoded data and a trellis error signal, the trellis error signal formed as a decision error of a selected previous state of a selected trellis path;

15 a linear feedforward equalizer, the linear feedforward equalizer having as input the received training signal during the training mode and a received data signal during data mode, the linear feedforward equalizer operatively coupled to the trellis decoder for adaptation to the first training error signal during training mode to provide a first plurality of coefficients $a(n)$ for equalization and for adaptation to the trellis error signal during data mode to modify the first plurality of coefficients $a(n)$ for adaptive equalization;

20 a training mode adaptive distortion and correlated noise canceller operative during training mode, an output of the training mode adaptive distortion and correlated noise canceller operatively coupled to an output of the linear feedforward equalizer to provide an input to the symbol decider of the trellis decoder, the training mode adaptive distortion and correlated noise canceller having as input a second training error signal, the second training error signal formed as a difference between the symbol decision and the received training signal subsequent to equalization, the training mode adaptive distortion and correlated noise canceller operatively coupled to the trellis 25 decoder for adaptation to the first training error signal to provide a second plurality of

coefficients $b(n)$ for equalization and a third plurality of coefficients $c(n)$ for correlated noise reduction; and

5 a data mode adaptive correlated noise canceller operative during data mode, an output of the data mode adaptive correlated noise canceller operatively coupled to a filtered output of the linear feedforward equalizer to provide an input to the trellis decoder, the data mode adaptive correlated noise canceller having as input a tentative error signal, the tentative error signal formed as a difference between a tentative symbol decision and a delayed received data signal subsequent to equalization, the data mode adaptive correlated noise canceller operatively coupled to the trellis decoder for
10 adaptation to the trellis error signal during data mode to modify the third plurality of coefficients $c(n)$ for adaptive correlated noise reduction.

13. The apparatus of claim 12, wherein the trellis decoder is further operative during data mode to determine a plurality of trellis paths, to determine a cumulative error
15 associated with each trellis path of the plurality of trellis paths, and to select a trellis path, from the plurality of trellis paths, having a smallest cumulative error, to form the selected trellis path.

14. The apparatus of claim 12, wherein the trellis decoder is further operative
20 to select an immediately previous state of the selected trellis path to form the selected previous state.

15. The apparatus of claim 12, wherein the data mode adaptive correlated noise canceller is further operative, when data has been precoded, to reset the third plurality of coefficients $c(n)$ to zero subsequent to training mode and prior to data mode.
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16. The apparatus of claim 12, wherein the tentative symbol decision and the delayed received data signal subsequent to equalization have one symbol time delay.

17. The apparatus of claim 12, further comprising:
a processor coupled to the training mode adaptive distortion and correlated
noise canceller, wherein the processor, when operative, is configured to determine a
fourth plurality of coefficients $t(n)$ as equal to a sum of the second plurality of
5 coefficients $b(n)$ plus the third plurality of coefficients $c(n)$ plus the result of a
convolution of the second plurality of coefficients $b(n)$ with the third plurality of
coefficients $c(n)$ ($t(n) = b(n) + c(n) + b(n)*c(n)$), and wherein the processor is further
configured to transfer the fourth plurality of coefficients $t(n)$ to the transmitter for
precoding of data for transmission.

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18. The apparatus of claim 12, wherein the training mode adaptive distortion
and correlated noise canceller is further configured to transfer the second plurality of
coefficients $b(n)$ and the third plurality of coefficients $c(n)$ to the transmitter for
precoding using a fourth plurality of coefficients $t(n)$, the fourth plurality of coefficients
15 $t(n)$ determined by the transmitter as equal to a sum of the second plurality of coefficients
 $b(n)$ plus the third plurality of coefficients $c(n)$ plus the result of a convolution of the
second plurality of coefficients $b(n)$ with the third plurality of coefficients $c(n)$ ($t(n) =$
 $b(n) + c(n) + b(n)*c(n)$).

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19. The apparatus of claim 12, wherein the filtered output of the linear
feedforward equalizer is generated by a filter having a transfer function of $(1 + C(z))$,
wherein $C(z)$ is a z-transform of the third plurality of coefficients $c(n)$.

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20. The apparatus of claim 12, wherein the training mode adaptive distortion

and correlated noise canceller further comprises:

a decision feedback adaptive filter operatively coupled to an output of the
linear feedforward equalizer, the decision feedback adaptive filter operatively coupled to
the symbol decider for input of the symbol decision, for adaptation to the first training
error signal and to provide the second plurality of coefficients $b(n)$ for equalization; and

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a noise predictor, the noise predictor having an output operatively coupled
to a combined output of the linear feedforward equalizer and the decision feedback

adaptive filter to provide an input to the symbol decider, the noise predictor having as input the second training error signal, and the noise predictor operatively coupled to the symbol decider for adaptation to the first training error signal to provide the third plurality of coefficients $c(n)$ for correlated noise reduction.

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21.

A method of correlated noise reduction, the method comprising:

(a) receiving a data signal to form a received data signal;

(b) determining a trellis error signal as a decision error of a selected previous state of a selected trellis path;

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(c) equalizing a received data signal utilizing a first plurality of equalization coefficients $a(n)$ to form an equalized data signal and modifying the first plurality of equalization coefficients $a(n)$ in response to the trellis error signal;

(d) determining a tentative error signal as a difference between a tentative symbol decision and a delayed equalized data signal;

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(e) reducing correlated noise in the equalized data signal utilizing a plurality of correlated noise reduction coefficients $c(n)$ and modifying the plurality of correlated noise reduction coefficients $c(n)$ in response to the trellis error signal and with input of the tentative error signal.

20 22.

The method of claim 21, wherein step (b) further comprises:

determining a plurality of trellis paths;

determining a cumulative error associated with each trellis path of the plurality of trellis paths; and

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selecting a trellis path, from the plurality of trellis paths, having a smallest cumulative error, to form the selected trellis path.

23.

The method of claim 21, wherein step (b) further comprises:

selecting an immediately previous state of the selected trellis path to form the selected previous state.

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24. The method of claim 21, wherein step (d) further comprises:
selecting the tentative symbol decision and the delayed equalized data
signal having one symbol time delay.

5 25. The method of claim 21, wherein step (c) further comprises:
filtering the equalized data signal utilizing a transfer function of $(1 +$
 $C(z))$, wherein $C(z)$ is a z-transform of the correlated noise reduction coefficients $c(n)$.

10 26. The method of claim 21, further comprising:
trellis decoding the received data signal subsequent to equalization and
correlated noise reduction.

15 27. The method of claim 21, further comprising, prior to step (a):
receiving a training signal to form a received training signal;
determining a first training error signal as a difference between a symbol
decision and the received training signal subsequent to equalization and correlated noise
reduction;
determining the first plurality of equalization coefficients $a(n)$ using the
received training signal and with adaptation to the first training error signal;

20 determining a second plurality of equalization coefficients $b(n)$ using the
symbol decision and with adaptation to the first training error signal;
determining a second training error signal as a difference between the
symbol decision and the received training signal subsequent to equalization; and
determining the plurality of correlated noise reduction coefficients $c(n)$ for

25 correlated noise reduction using the second training error signal and with adaptation to
the first training error signal.

28. The method of claim 27, further comprising:
determining a plurality of precoding coefficients $t(n)$ as equal to a sum of
30 the second plurality of equalization coefficients $b(n)$ plus the plurality of correlated noise
reduction coefficients $c(n)$ plus the result of a convolution of the second plurality of

equalization coefficients $b(n)$ with the plurality of correlated noise reduction coefficients $c(n)$ ($t(n) = b(n) + c(n) + b(n)*c(n)$).

29. The method of claim 21, further comprising, prior to step (a):

5 receiving a training signal to form a received training signal;
determining a first training error signal as a difference between a symbol decision and the received training signal subsequent to equalization and correlated noise reduction;

10 determining the first plurality of equalization coefficients $a(n)$ using the received training signal and with adaptation to the first training error signal;

determining a second training error signal as a difference between the symbol decision and the received training signal subsequent to equalization; and

15 determining the plurality of correlated noise reduction coefficients $c(n)$ for correlated noise reduction using the second training error signal and with adaptation to the first training error signal.

~~30.~~ An apparatus for correlated noise reduction, the apparatus comprising:

means for receiving a data signal to form a received data signal;
means for determining a trellis error signal as a decision error of a selected 20 previous state of a selected trellis path;

means for equalizing a received data signal utilizing a first plurality of equalization coefficients $a(n)$ to form an equalized data signal and modifying the first plurality of equalization coefficients $a(n)$ in response to the trellis error signal;

25 means for determining a tentative error signal as a difference between a tentative symbol decision and a delayed equalized data signal;

means for reducing correlated noise in the equalized data signal utilizing a plurality of correlated noise reduction coefficients $c(n)$ and modifying the plurality of correlated noise reduction coefficients $c(n)$ in response to the trellis error signal and with input of the tentative error signal.

31. The apparatus of claim 30, further comprising:
means for determining a plurality of trellis paths;
means for determining a cumulative error associated with each trellis path
of the plurality of trellis paths; and
5 means for selecting a trellis path, from the plurality of trellis paths, having
a smallest cumulative error, to form the selected trellis path.

32. The apparatus of claim 30, further comprising:
means for selecting an immediately previous state of the selected trellis
10 path to form the selected previous state.

33. The apparatus of claim 30, further comprising:
means for selecting the tentative symbol decision and the delayed
15 equalized data signal having one symbol time delay.

34. The apparatus of claim 30, further comprising:
means for filtering the equalized data signal utilizing a transfer function of
(1 + C(z)), wherein C(z) is a z-transform of the correlated noise reduction coefficients
c(n).
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35. The apparatus of claim 30, further comprising:
means for trellis decoding the received data signal subsequent to
equalization and correlated noise reduction.

25 36. The apparatus of claim 30, further comprising:
means for receiving a training signal to form a received training signal;
means for determining a first training error signal as a difference between
a symbol decision and the received training signal subsequent to equalization and
correlated noise reduction;
30 means for determining the first plurality of equalization coefficients a(n)
using the received training signal and with adaptation to the first training error signal;

means for determining a second plurality of equalization coefficients $b(n)$ using the symbol decision and with adaptation to the first training error signal;

means for determining a second training error signal as a difference between the symbol decision and the received training signal subsequent to equalization;

5 and

means for determining the plurality of correlated noise reduction coefficients $c(n)$ for correlated noise reduction using the second training error signal and with adaptation to the first training error signal.

10 37. The apparatus of claim 36, further comprising:

means for determining a plurality of precoding coefficients $t(n)$ as equal to a sum of the second plurality of equalization coefficients $b(n)$ plus the plurality of correlated noise reduction coefficients $c(n)$ plus the result of a convolution of the second plurality of equalization coefficients $b(n)$ with the plurality of correlated noise reduction coefficients $c(n)$ ($t(n) = b(n) + c(n) + b(n)*c(n)$).

38. The apparatus of claim 30, further comprising:

means for receiving a training signal to form a received training signal;

20 means for determining a first training error signal as a difference between a symbol decision and the received training signal subsequent to equalization and correlated noise reduction;

means for determining the first plurality of equalization coefficients $a(n)$ using the received training signal and with adaptation to the first training error signal;

25 means for determining a second training error signal as a difference between the symbol decision and the received training signal subsequent to equalization; and

means for determining the plurality of correlated noise reduction coefficients $c(n)$ for correlated noise reduction using the second training error signal and with adaptation to the first training error signal.

39.

A system for reduction of correlated noise during data transmission, the system comprising:

a transmitter, the transmitter operative to transmit a training signal and to transmit a data signal; and

5 a receiver couplable to the transmitter via a communication channel, the receiver further comprising:

a trellis decoder, the trellis decoder operative to provide decoded data and a trellis error signal, the trellis error signal formed as a decision error of a selected previous state of a selected trellis path;

10 a linear feedforward equalizer, the linear feedforward equalizer having as input a received data signal, the linear feedforward equalizer operatively coupled to the trellis decoder for adaptation to the trellis error signal to modify a first plurality of equalization coefficients $a(n)$; and

15 a noise predictor, the noise predictor operatively coupled to the linear feedforward equalizer to provide an input to the trellis decoder, the noise predictor having as input a tentative error signal, the tentative error signal formed as a difference between a tentative symbol decision and a delayed received data signal subsequent to equalization, the noise predictor operatively coupled to the trellis decoder for adaptation to the trellis error signal to modify a plurality of correlated noise reduction coefficients $c(n)$.

20 40. The system of claim 39, wherein the trellis decoder is further operative to determine a plurality of trellis paths, to determine a cumulative error associated with each trellis path of the plurality of trellis paths, and to select a trellis path, from the plurality of trellis paths, having a smallest cumulative error, to form the selected trellis path.

25 41. The system of claim 39, wherein the trellis decoder is further operative to select an immediately previous state of the selected trellis path to form the selected previous state.

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42. The system of claim 39, wherein the tentative symbol decision and the delayed received data signal subsequent to equalization are selected at a time of one symbol time delay.

5 43. The system of claim 39, wherein for precoded data, an output of the linear feedforward equalizer is filtered utilizing a transfer function of $(1 + C(z))$, wherein $C(z)$ is a z-transform of the correlated noise reduction coefficients $c(n)$.

10 44. The system of claim 39, wherein the receiver further comprises:
a decision feedback adaptive filter operatively coupled to an output of the linear feedforward equalizer.

15 45. The system of claim 39, wherein for precoded data:
the trellis decoder further has a symbol decider operative during a training mode to provide a symbol decision and a first training error signal, the first training error signal formed as a difference between the symbol decision and a received training signal subsequent to equalization and correlated noise reduction;
the linear feedforward equalizer further has as input the received training signal during the training mode, the linear feedforward equalizer operatively coupled to the trellis decoder for adaptation to the first training error signal during training mode to provide the first plurality of coefficients $a(n)$ for equalization;
the decision feedback adaptive filter is further operatively coupled to the symbol decider for input of the symbol decision, for adaptation to the first training error signal and to provide a second plurality of equalization coefficients $b(n)$; and
20 the noise predictor, further having an output operatively coupled to a combined output of the linear feedforward equalizer and the decision feedback adaptive filter to provide an input to the symbol decider, the noise predictor having as input a second training error signal, the second training error signal formed as a difference between the symbol decision and the received training signal subsequent to equalization, and the noise predictor operatively coupled to the symbol decider for adaptation to the
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first training error signal to provide the plurality of correlated noise reduction coefficients $c(n)$.

46. The system of claim 45, further comprising:

5 a processor operatively coupled to the decision feedback adaptive filter and to the noise predictor, wherein the processor, when operative, is configured to determine a plurality of precoding coefficients $t(n)$ as equal to a sum of the second plurality of equalization coefficients $b(n)$ plus the plurality of correlated noise reduction coefficients $c(n)$ plus the result of a convolution of the second plurality of equalization 10 coefficients $b(n)$ with the plurality of correlated noise reduction coefficients $c(n)$ ($t(n) = b(n) + c(n) + b(n)*c(n)$); and

15 wherein the processor is further configured to transfer the plurality of precoding coefficients $t(n)$ to the transmitter for precoding of data for transmission to form the data signal.

47. The system of claim 45, wherein the transmitter is further configured for precoding of data for transmission to form the data signal using a plurality of precoding coefficients $t(n)$ determined by the transmitter as equal to a sum of the second plurality of equalization coefficients $b(n)$ plus the plurality of correlated noise reduction coefficients 20 $c(n)$ plus the result of a convolution of the second plurality of equalization coefficients $b(n)$ with the plurality of correlated noise reduction coefficients $c(n)$ ($t(n) = b(n) + c(n) + b(n)*c(n)$).

48. The system of claim 39, wherein for non-precoded data:

25 the trellis decoder further has a symbol decider operative during a training mode to provide a symbol decision and a first training error signal, the first training error signal formed as a difference between the symbol decision and a received training signal subsequent to equalization and correlated noise reduction;

30 the linear feedforward equalizer further has as input the received training signal during the training mode, the linear feedforward equalizer operatively coupled to

the trellis decoder for adaptation to the first training error signal during training mode to provide the first plurality of coefficients $a(n)$ for equalization; and

the noise predictor further has as input a second training error signal, the second training error signal formed as a difference between the symbol decision and the received training signal subsequent to equalization, and the noise predictor operatively coupled to the symbol decider for adaptation to the first training error signal to provide the plurality of correlated noise reduction coefficients $c(n)$.

49. An apparatus for correlated noise reduction, the apparatus comprising:

10 a trellis decoder, the trellis decoder operative to provide decoded data and a trellis error signal, the trellis error signal formed as a decision error of a selected previous state of a selected trellis path;

15 a linear feedforward equalizer, the linear feedforward equalizer having as input a received data signal, the linear feedforward equalizer operatively coupled to the trellis decoder for adaptation to the trellis error signal to modify a first plurality of equalization coefficients $a(n)$; and

20 a noise predictor, the noise predictor operatively coupled to the linear feedforward equalizer to provide an input to the trellis decoder, the noise predictor having as input a received data signal subsequent to equalization, the noise predictor operatively coupled to the trellis decoder for adaptation to the trellis error signal to modify a plurality of correlated noise reduction coefficients $c(n)$.

50. The apparatus of claim 49, wherein the trellis decoder is further operative to determine a plurality of trellis paths, to determine a cumulative error associated with 25 each trellis path of the plurality of trellis paths, and to select a trellis path, from the plurality of trellis paths, having a smallest cumulative error, to form the selected trellis path.

51. The apparatus of claim 49, wherein the trellis decoder is further operative 30 to select an immediately previous state of the selected trellis path to form the selected previous state.

52. The apparatus of claim 49, further comprising:
a decision feedback adaptive filter operatively coupled to an output of the
linear feedforward equalizer.

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53. The apparatus of claim 52, wherein for precoded data:
the trellis decoder further has a symbol decider operative during a training
mode to provide a symbol decision and a first training error signal, the first training error
signal formed as a difference between the symbol decision and a received training signal
10 subsequent to equalization and correlated noise reduction;
the linear feedforward equalizer further has as input the received training
signal during the training mode, the linear feedforward equalizer operatively coupled to
the trellis decoder for adaptation to the first training error signal during training mode to
provide the first plurality of coefficients $a(n)$ for equalization;

15 the decision feedback adaptive filter is further operatively coupled to the
symbol decider for input of the symbol decision, for adaptation to the first training error
signal and to provide a second plurality of equalization coefficients $b(n)$; and

20 the noise predictor, further having an output operatively coupled to a
combined output of the linear feedforward equalizer and the decision feedback adaptive
filter to provide an input to the symbol decider, the noise predictor having as input a
second training error signal, the second training error signal formed as a difference
between the symbol decision and the received training signal subsequent to equalization,
and the noise predictor operatively coupled to the symbol decider for adaptation to the
first training error signal to provide the plurality of correlated noise reduction coefficients
25 $c(n)$.

54. The apparatus of claim 53, further comprising:
a processor operatively coupled to the decision feedback adaptive filter
and to the noise predictor, wherein the processor, when operative, is configured to
30 determine a plurality of precoding coefficients $t(n)$ as equal to a sum of the second
plurality of equalization coefficients $b(n)$ plus the plurality of correlated noise reduction

coefficients $c(n)$ plus the result of a convolution of the second plurality of equalization coefficients $b(n)$ with the plurality of correlated noise reduction coefficients $c(n)$ ($t(n) = b(n) + c(n) + b(n)*c(n)$); and

5 wherein the processor is further configured to transfer the plurality of precoding coefficients $t(n)$ to a transmitter for precoding of data for transmission.

55. The apparatus of claim 53, further comprising:

a first transmitter configured to transfer the plurality of equalization coefficients $b(n)$ and the plurality of correlated noise reduction coefficients $c(n)$ to a second transmitter for precoding using a plurality of precoding coefficients $t(n)$ determined by the second transmitter as equal to a sum of the second plurality of equalization coefficients $b(n)$ plus the plurality of correlated noise reduction coefficients $c(n)$ plus the result of a convolution of the second plurality of equalization coefficients $b(n)$ with the plurality of correlated noise reduction coefficients $c(n)$ ($t(n) = b(n) + c(n) + b(n)*c(n)$).

56. The apparatus of claim 49, wherein for non-precoded data:

the trellis decoder further has a symbol decider operative during a training mode to provide a symbol decision and a first training error signal, the first training error signal formed as a difference between the symbol decision and a received training signal subsequent to equalization and correlated noise reduction;

the linear feedforward equalizer further has as input the received training signal during the training mode, the linear feedforward equalizer operatively coupled to the trellis decoder for adaptation to the first training error signal during training mode to provide the first plurality of coefficients $a(n)$ for equalization; and

the noise predictor further has as input a second training error signal, the second training error signal formed as a difference between the symbol decision and the received training signal subsequent to equalization, and the noise predictor operatively coupled to the symbol decider for adaptation to the first training error signal to provide the plurality of correlated noise reduction coefficients $c(n)$.

57. An apparatus for correlated noise reduction, the apparatus having a training mode and having a data mode, the apparatus operative during training mode to receive a training signal from a transmitter and operative during data mode to receive a data signal from the transmitter, the apparatus comprising:

5 a trellis decoder, the trellis decoder having a symbol decider operative during the training mode to provide a symbol decision and a first training error signal, the first training error signal formed as a difference between the symbol decision and a received training signal subsequent to equalization and correlated noise reduction, the trellis decoder operative during the data mode to provide decoded data and a trellis error signal, the trellis error signal being a decision error of an immediately previous state of a selected trellis path of a plurality of trellis paths, the selected trellis path having a smallest cumulative error of the plurality of trellis paths;

10 15 a linear feedforward equalizer, the linear feedforward equalizer having as input the received training signal during the training mode and a received data signal during data mode, the linear feedforward equalizer operatively coupled to the trellis decoder for adaptation to the first training error signal during training mode to provide a first plurality of equalization coefficients $a(n)$ and for adaptation to the trellis error signal during data mode to modify the first plurality of equalization coefficients $a(n)$ for adaptive equalization;

20 25 a decision feedback adaptive filter operatively coupled to an output of the linear feedforward equalizer and operatively coupled to the symbol decider for input of the symbol decision, for adaptation to the first training error signal and to provide a second plurality of equalization coefficients $b(n)$ for data transmission precoding;

30 a noise predictor, the noise predictor operatively coupled to combined output of the linear feedforward equalizer and the decision feedback adaptive filter to provide an input to the trellis decoder, the noise predictor having as input a second training error signal during training mode, the second training error signal formed as a difference between the symbol decision and the received training signal subsequent to equalization, the noise predictor operatively coupled to the trellis decoder for adaptation to the first training error signal during training mode to provide a plurality of correlated noise reduction coefficients $c(n)$ for data transmission precoding, the noise predictor

further having as input a tentative error signal during data mode, the tentative error signal formed as a difference between a tentative symbol decision and a delayed received data signal subsequent to equalization, the tentative symbol decision and the delayed received data signal subsequent to equalization having one symbol time delay, the noise predictor

5 further operatively coupled to the trellis decoder for adaptation to the trellis error signal during data mode to initially reset the plurality of correlated noise reduction coefficients $c(n)$ to zero and to subsequently modify the plurality of correlated noise reduction coefficients $c(n)$ for adaptive correlated noise reduction; and

a processor operatively coupled to the decision feedback adaptive filter

10 and to the noise predictor, wherein the processor, when operative, is configured to determine a plurality of precoding coefficients $t(n)$ as equal to a sum of the second plurality of equalization coefficients $b(n)$ plus the plurality of correlated noise reduction coefficients $c(n)$ plus the result of a convolution of the second plurality of equalization coefficients $b(n)$ with the plurality of correlated noise reduction coefficients $c(n)$ ($t(n) =$
15 $b(n) + c(n) + b(n)*c(n)$), and wherein the processor is further configured to transfer the plurality of precoding coefficients $t(n)$ to the transmitter for precoding of data for transmission.